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Investigation of the heat transfer behaviour of a polymer solar collector for different manifold configurations

D. Missirlis [a], G. Martinopoulos [b,c,*], G. Tsilingiridis [c], K. Yakinthos [a], N. Kyriakis [c,1]

[a] Aristotle University of Thessaloniki, Department of Mechanical Engineering, Laboratory of Fluid Mechanics and Turbomachinery, EL 54124 Thessaloniki, Greece
[b] International Hellenic University, School of Science and Technology, 14th km Thessaloniki – Moudania, EL 570 01 Thermi – Thessaloniki, Greece
[c] Aristotle University of Thessaloniki, Department of Mechanical Engineering, Process Equipment Design Laboratory, POB 487, EL 54124 Thessaloniki, Greece

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ABSTRACT

In order to further promote the utilization of solar thermal systems, solar collectors need to become more efficient and cost effective. This can be accomplished by a variety of methods, either by using lower cost materials, or/and by increasing their thermal efficiency by novel design. The current work presents such an effort dealing with the investigation of the heat transfer behaviour of a novel polymer solar collector for different manifold configurations with computational fluid dynamics (CFD).

A CFD model that has previously been developed and validated is used to investigate different collector manifold configurations in order to optimize flow field development and to increase collector thermal efficiency.

The investigation was carried-out for a wide range of inlet temperature conditions covering the expected operational range of the solar collector and the proposed collector's manifolds provided a considerable increase of the solar energy exploited by the collector without any increase in the manufacturing cost.

1. Introduction

Renewable energy in general, and solar energy in specific, offers a viable solution for today's energy needs. Total world primary renewable energy supply, including traditional biomass, grew from 1319 million tonnes of oil equivalent (Mtoe) in 2000 to 1590 Mtoe in 2008 with a share in total energy supply of 13% [1]. Solar Energy for thermal applications is currently the most widely used application of renewable energy sources. Solar energy in the form of solar thermal systems accounted for 195.8 GW_{th} worldwide with more than 36 GW_{th} in the EU alone, in 2010 [2,3].

Higher penetration for solar heating systems depends on technology developments related to simplicity in manufacturing and use and their economic viability among others. Depending on the application, heat is needed in the following temperature ranges:

- 45 °C–90 °C for space heating (depending on the technology used),
- 50 °C–60 °C for domestic hot water,
- 60 °C–400 °C for industrial processes.

In order to minimize the production cost of current solar collectors, new materials of lower cost and preferably more environmental friendly must substitute the ones that are employed today, without any deterioration of collector efficiency.

A CFD model that has previously been developed and validated is used to investigate different collector manifold configurations in order to optimize flow field development and to increase collector thermal efficiency.

2. Solar collector description

The most commonly used solar system is the one producing hot water for domestic use. The basic unit of such a system is the solar collector. Among the solar collector configurations used, the most common is the flat plate one [3].

Typical flat plate collectors are either corrugated, bond duct or tube-in-plate type and their performance depends on various

* Corresponding author. International Hellenic University, School of Science and Technology, 14th km Thessaloniki – Moudania, EL 570 01 Thermi – Thessaloniki, Greece. Tel.: +30 2310807533; fax: +30 2310474590.
E-mail addresses: g.martinopoulos@ihu.edu.gr, martin@meng.auth.gr (G. Martinopoulos).

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design parameters, including the number of covers, the type and thickness of glazing, the anti-reflecting coating on cover glass, the type of coating on the absorber plate, the spacing between the absorber and the inner glass, the type and thickness of insulation used, etc.

Flat plate collectors have been studied by many researchers either regarding their thermal characteristics like, Hottel and Woertz [4], Bliss [5], Nahar and Garg [6], Francken [7], Sookdeo and Siddiqui [8], Eisenmann et al. [9] and others, either regarding their environmental performance like, Kalogirou [10], Martinopoulos et al. [11], Martinopoulos [12] and others.

Operation parameters affecting the performance of a solar collector are the mass flow rate of fluid, the amount of incident solar radiation, the inlet and ambient temperatures and sky conditions, to name a few.

In recent years, a number of researchers have adopted the use of polymers in solar collector design since their cost and physical properties make the volume production of lightweight low-cost and corrosion resistance collectors possible. All-polymeric solar collectors are wide spread, mainly in the form of low cost unglazed ones for heating swimming pools [13], with an installed capacity of more than 21.4 GW_{th} worldwide [2].

In the current work a polymer collector that has similar or better technical characteristics to those of typical flat plate collectors at the same operational uses for a wide variety of operating temperatures but with reduced cost and lighter is investigated through CFD in order to optimize manifold placement and thus its thermal behaviour and efficiency.

CFD analysis of the aforementioned collector showed that large recirculation regions were formed as a result of the design of the collector geometry and more specifically, by the positioning of the inlet and outlet pipes [14].

The collector comprises all the usual components of a typical one. The main difference is that instead of a metal absorber, a black fluid acts as both absorber and heat carrier. The fluid flows in a transparent polymer honeycomb construction. This particular type of collector combines low cost, low weight and simplicity of manufacture and can be used in all applications requiring low to mid temperature heat with an indirect circulation of the heat transfer fluid. The cross-section of the collector is shown in Fig. 1 while the dimensions of the collector and the inlet and outlet position of the manifold are presented in Fig. 2. More details regarding the collector's technical characteristics can be found in Table 1.

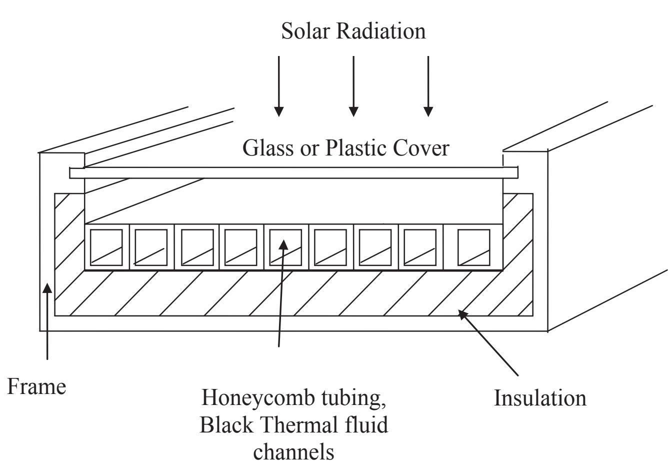

Fig. 1. Schematic presentation of the examined solar collector.

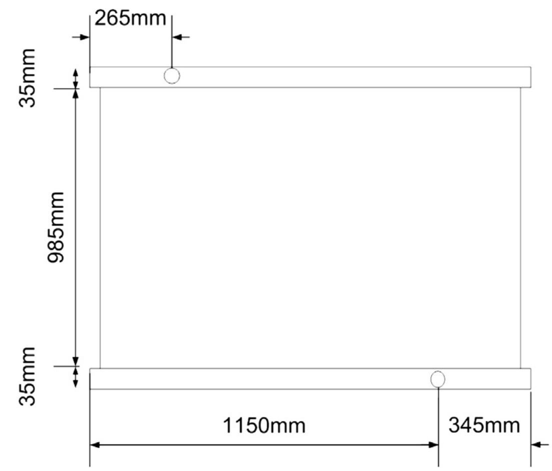

Fig. 2. Base case manifolds configuration.

3. CFD modelling

The optimization of energy exchange devices is one of the most important aspects in engineering applications. Towards this direction, numerical methods and techniques are used since they can provide significant design advantages regarding time and cost. Similar efforts have been so far presented in international literature in the works of Martinopoulos et al. [14], Gertzos et al. [15], Gertzos and Caouris [16], Gertzos et al. [17], Farahat et al. [18], Selmi et al. [19], Henderson et al. [20], Varol and Oztop [21], Villar et al. [22] among others.

The basic solar collector geometry under investigation consists of a honeycomb hydraulic construction, through which the black absorbing fluid passes, having a large number of rectangular flow channels placed inside. If one attempted to model the precise honeycomb collector geometry, a high number of computational cells would have to be used in order to resolute properly all areas were significant flow variations would be present (i.e. channel solid walls). This necessity, together with the large, regarding CFD computations, dimensions of the collector, would lead to time consuming CFD computations and high CPU and memory requirements. All of the above would nullify the advantage of numerical computations since the amount of time required would increase noticeably. Thus, to overcome this problem, a macroscopic modelling of the solar collector geometry can be used where the honeycomb collector geometry was modelled as a porous medium having predefined pressure loss behaviour. The use of porous medium approach in order to model accurately the mean heat transfer and pressure drop behaviour of devices of geometry which is either too complicated or contain an extreme number of flow passages

Table 1
Collector technical specifications.

Total area	1.448 m^2
Glazing area	1.252 m^2
Absorber area	1.252 m^2
Number of glazings	1
Glazing material	3 mm solid transparent UV stabilized LEXAN
Heat carrier fluid	Water and Indian Ink solution (1000:1)
Absorber	Transparent UV stabilized honeycombed LEXAN sheet (10 mm)
Headers	Acrylic 8 mm rectangular
Fluid weight	~14 kg
Back insulation	Honeycombed LEXAN sheet with a 10 mm thickness filled with nanogel ($k = 0.018$ $Wm^{-1}K^{-1}$)
Side insulation	Extruded PU 30 mm ($\lambda = 0.03$ Wm^{-2} K^{-1})